

# Assessment of Crusader

## The Army's Next Self-Propelled Howitzer and Resupply Vehicle

John M. Matsumura  
Randall Steeb  
John Gordon IV

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1998

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The research described in this report was sponsored by the United States Army under Contract No. DASW01-96-C-0004.

ISBN: 0-8330-2596-1

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Published 1998 by RAND

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John M. Matsumura  
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*MR-930-A*

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Prepared for the  
United States Army

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## PREFACE

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This document summarizes the results from a six-week special assistance study conducted by RAND's Arroyo Center. This study was requested by the Assistant Vice Chief of Staff of the Army and was coordinated with the Office of the Deputy Chief of Staff for Operations and Plans (DCSOPS). The specific objective of the special assistance effort was to explore the utility of the Crusader system to the future of the Army. Along these lines, specific questions were asked about Crusader's ability to provide firepower on the future battlefield and to serve as a major technology "carrier" into the Army After Next (AAN) era. This document not only includes our answers to the questions posed by DCSOPS but also addresses some of the other issues that may surface in considering the relative need for a state-of-the-art self-propelled howitzer (SPH) in light of other U.S. Army interests. Thus, it should be of interest to defense acquisition officials and policymakers.

The research was carried out in the Force Development and Technology Program of RAND's Arroyo Center, a federally funded research and development center sponsored by the United States Army.

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## SUMMARY

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### BACKGROUND

The Army faces a dilemma with regard to its self-propelled howitzer fleet. On the one hand, it is in the process of upgrading its 155mm Paladin (M109 A6) howitzers, giving them on-board capability to orient themselves, compute firing data, and fire rounds responsively. These improvements notwithstanding, the Paladin version of the self-propelled howitzer (SPH) does not overcome several shortcomings noted during the Persian Gulf War, most notably limited mobility and slow rate of fire. Furthermore, foreign field artillery systems are gaining capabilities that significantly outstrip those of the Paladin, increasing the likelihood that U.S. forces might one day face opponents with more capable systems. Inherent limitations of the Paladin chassis tend to limit any further upgrades.

On the other hand, the Crusader system that the Army is considering as a replacement for the Paladin not only overcomes the deficiencies but also holds out the promise of being able to carry out new fire support missions. But the Crusader is expensive, and it does not mesh well with the Army's far-term vision of the future.<sup>1</sup> Thus, the Army's dilemma is whether to retain the Paladin system and its known deficiencies in the hope of perhaps developing a system that will both overcome these shortcomings and better fit the Army's vision of warfighting in the future or to continue to invest in Crusader, knowing it will be in the force well into the Army After Next era.

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<sup>1</sup>Current visions of future ground forces, including Army After Next, tend to emphasize lighter-weight, and hence more deployable, combat vehicles with dramatically increased maneuverability.

## RESEARCH OBJECTIVE

The specific objective of this quick-response, special assistance effort was to explore the utility of the Crusader system to the future of the Army. Along these lines, specific questions were asked about Crusader's ability to provide firepower on the future battlefield and to serve as a major technology "carrier" into the Army After Next (AAN) era.

- What does Crusader provide to Army XXI?
- What increase in the application of fires does Crusader provide over current capabilities?
- What technologies does Crusader carry to the AAN weapon systems?

We not only attempted to answer these questions but also addressed other issues that have surfaced in assessing the relative need for a state-of-the-art SPH in light of other U.S. Army interests.

## WHAT DOES CRUSADER PROVIDE TO ARMY XXI?

An evaluation of the operational requirements document suggests that Crusader will have significant improvements in firepower, mobility (both in terms of offroad speed and dash capability), survivability enhancement, and manpower reduction. Many of these improvements are synergistic and may result in further battlefield advantage, such as survivability enhancements resulting from smaller crews operating fully inside the vehicle, greater dash speeds, faster attrition of the enemy, and special susceptibility-reduction measures. *We find that Crusader represents a system that is very capable of the high-tempo operations that are an essential aspect of an Army XXI force.*

## WHAT INCREASE IN THE APPLICATION OF FIRES DOES CRUSADER PROVIDE OVER CURRENT CAPABILITIES?

A number of Crusader's features are expected to increase the application of fires. For example, the volume of fire compared to Paladin will be much greater, due to a number of factors: the autoloader

provides fast assembly and loading of rounds, active pumped liquid cooling of the gun lowers temperatures below that at which charges “cook off” (ignite as they are loaded), and highly automated resupply allows a 60-round reload/refuel time of 12 minutes (about half the time for Paladin to reload only). A single Crusader system produces a substantially higher volume of fire in both short few-minute periods such as shoot-and-scoot and in longer-duration high-volume missions where the SPH might be stationary. In addition to volume of fire, Crusader further improves range and projectile flyout time (i.e., the time it takes the projectile to reach its target).

Collectively, these improvements could offer several advantages. Crusader could accomplish preparatory fires, general support, and counterfire more quickly, generating greater shock effect on the enemy than is possible with current capabilities. Alternatively, missions could be carried out over a broader area in the same time as with current capabilities, reducing the intensity of ensuing direct-fire battles and lessening the need for mutual support among units. Greater mission scope could also lessen the requirements for close air support and free up other assets such as MLRS for other missions. Finally, the efficiency of Crusader may allow a battery to carry out the mission of a battalion, or a single gun to replace a platoon, so that force size, logistics burden, and deployment load may be reduced. *Because of its greatly improved firepower, one can begin to postulate new missions that might have not been possible with the Paladin system, or other SPHs for that matter.*

## **WHAT TECHNOLOGIES DOES CRUSADER CARRY TO THE ARMY AFTER NEXT?**

As currently envisioned, the AAN concept represents a revolutionary approach to battle. One of the fundamental requirements of AAN is operations at a high tempo, with agile, air-mobile battle units operating over large areas. These units are expected to coordinate with heavier Army XXI exploitation units to outmaneuver and shock the enemy with quick thrusts and massed fires. The forces will also rely on information dominance and integrated operations to gain comprehensive situation awareness while denying the enemy knowledge of our actions.

Several Crusader technologies have a high degree of applicability to the AAN battle force. Because accurate, real-time information will be a fundamental requirement for AAN forces, capabilities such as *automated situation awareness and embedded diagnostics* will be critical. The more lethal future battlefield will also place a premium on quality *nuclear biological chemical (NBC) protection and hit/detection avoidance*.

Other Crusader technologies such as *advanced armor and improved mobility* should be important for future combat vehicles, such as the future tank and infantry fighting vehicle, but may be of somewhat less importance to the lightweight air-mobile elements of AAN battle units. Probably of less importance to AAN are technologies such as Crusader's liquid-cooled cannon and projectile tracking system. This is because smart and brilliant munitions are expected to proliferate, and these may offset some of the need for round-to-round gun accuracy and volume of fires.

These advanced technologies do not obviate the issue that weight remains a major problem for Crusader in the AAN battle force concept. At a combat loaded weight of roughly 55 tons each for the self-propelled howitzer and the resupply vehicle (RSV), the concept does not mesh with the notional (15-ton) airliftable combat vehicles associated with the AAN battle force.<sup>2</sup> Although Crusader will likely be around during the first portion of the AAN era (30 years out) and may fit into many (non-battle-force) components in the AAN vision, the technologies and architecture of Crusader would have to be completely rethought to move it into a lower weight class. *Altogether, while the Crusader SPH may not directly fit into such far-future concepts for ground warfare, several of its technologies can still serve as a starting point for demonstrating, developing, and refining them so that they can be applied to a lighter-weight system in the future.*

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<sup>2</sup>Looking out 20 to 30 years from now, "legacy systems" will likely be a major part of the ground force even in the AAN vision. Although Crusader may not be suitable for providing support to this new class of AAN "air-mechanized" combat vehicles (or other more conservative alternatives), it will likely serve well in supporting those legacy systems for which it was designed.

## CONCLUSIONS

Given its acquisition cost, timing, and the current budget environment, the need for Crusader among other U.S. Army priorities is likely to be examined and reexamined. At a different level, the number of platforms necessary is also likely to be reconsidered.<sup>3</sup> In the context of this study, many issues were examined but not resolved given the study's limited scope and time frame.<sup>4</sup> We do note that there appear to be at least two key perspectives that challenge the need for the Crusader system.

For one, there are those who believe that cannon-based self-propelled fire support is essential to the future Army (as it has been for the past fifty years) but believe that either a Paladin, a modified/improved Paladin, or foreign system can accomplish the job. Secondly, there are those who believe that cannon-based self-propelled fire support is less essential to the future of the Army, and they think that advances in rocket artillery and submunitions or new technologies such as fiber-optically guided missiles will be able to perform an increasing number of missions that were previously accomplished by cannons.

In the first case, no alternatives to Crusader meet the operational requirements. Although we note the possibility for Paladin to meet some of the requirements, its chassis limitations make it unlikely to meet all of them. Likewise, foreign systems currently fall short of requirements, and in some cases these systems are designed to meet other operational concepts.<sup>5</sup> However, it is possible that foreign systems, such as PzH 2000, can be modified to better match the U.S. Army need. *Nonetheless, assuming the operational requirements are valid and are ultimately met by Crusader, it appears to be the most costly but also the most advanced SPH/RSV in the world.*

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<sup>3</sup>If at least some Crusaders (or a foreign alternative) are not acquired soon, there may be a shortfall in capability with Paladin for several decades. Any new artillery system may then have to compete for scarce acquisition dollars at the time the Army is upgrading its other combat vehicles (e.g., future main battle tank and future infantry fighting vehicle).

<sup>4</sup>The scope of the study was largely defined by DCSOPS, and it was conducted at their request in a six-week period.

<sup>5</sup>Personal communications with U.S. Army Artillery School representatives.

In the second case, while it is beneficial, if not essential, to postulate how ground warfare might change in the future, it is not yet prudent to make key acquisition decisions based on such concepts. Crusader is a brand new system that uses a long-established method for providing fire support, one that many see as dated in light of new technologies. This is perhaps the key criticism. However, many alternatives constitute brand new systems that could operate within yet-unproven concepts. *If new concepts and the associated noncannon alternatives are pursued in lieu of Crusader, they may ultimately constitute less robust and/or more expensive solutions in the future. Perhaps more importantly, though, if new concepts do not pan out, the safety and security of the forces that are put on the ground can ultimately be compromised.*

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## ACKNOWLEDGMENTS

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The authors would like to acknowledge the contributions of the many individuals involved with this work. From the U.S. Army Field Artillery School, COL Michael Cuff, LTC Michael Souder, MAJ Warren O'Donnel, and LTC James Cummings provided operational and technical information of different U.S. Army field artillery systems, including platforms and munitions. From PM Crusader, Mr. Kevin Fahey and Mr. Mark Otken provided programmatic and technical data on the Crusader system. From PM Paladin, Mr. Carol Gagnon provided technical and acquisition information on Paladin. From the National Ground Intelligence Center, Mr. Michael Holthus provided detailed information on current threat artillery systems and expectations for the future. Mr. Joseph Stallings provided an overview of Vector Research, Inc. (VRI) analyses assessing the Crusader system. Mr. David Napoliello and his team at United Defense Limited Partnership (UDLP) provided detailed assessments of Crusader technologies. COL Matthew Finley, COL Charles Rash, LTC James Boozer, and CPT Kevin Milton from DCSOPS provided data and guidance on many aspects of the research.

At RAND, Dr. Kenneth Horn and Mr. James Quinlivan provided guidance throughout the research process. LTC Mark Lees, Senior Army Fellow at the Arroyo Center, and Scot Eisenhard provided operational expertise and technical information on cannon performance. Gail Halverson provided the analytic simulation support to this research. June Kobashigawa finalized the manuscript, and Nikki Shacklett edited. Jerry Sollinger, Russell Glenn, and Donald Stevens provided thorough and timely technical reviews of this document.

The authors are solely responsible for the information contained in this report.



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## ABBREVIATIONS

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AAN	Army After Next
ACTD	Advanced Concept Technology Demonstration
AD	Armor Division
ADHPM	Artillery Delivered High Precision Munition
AFATDS	Advanced Field Artillery Tactical Data System
ATACMS	Army Tactical Missile System
BAT	Brilliant Anti-Tank
DARPA	Defense Advanced Research Projects Agency
DCSOPS	Deputy Chief of Staff for Operations and Plans
DMZ	Demilitarized Zone
DPICM	Dual-Purpose Improved Conventional Munitions
EFOG-M	Enhanced Fiber-Optically Guided Missile
FIFV	Future Infantry Fighting Vehicle
FLOT	Forward Line of Own Troops
FMBT	Future Main Battle Tank
GPS	Global Positioning System
HE	High Explosive
ICM	Improved Conventional Munitions

ID	Infantry Division
INS	Inertial Navigation System
JSOW	Joint Standoff Weapon
MACS	Modular Artillery Charge System
MLRS	Multiple Launch Rocket System
MOFA	Multi-Option Fuze, Artillery
MRL	Multiple Rocket Launcher
NBC	Nuclear, Biological, Chemical
NEA	Northeast Asia
NGIC	National Ground Intelligence Center
ORD	Operational Requirements Document
RAP	Rocket-Assisted Projectile
RSTA	Reconnaissance, Surveillance, and Target Acquisition
RSV	Resupply Vehicle
SADARM	Sense and Destroy Armor
SPH	Self-Propelled Howitzer
UAV	Uninhabited Aerial Vehicle
UGF	Underground Facility
UGV	Unmanned Ground Vehicle

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**THE FIRE SUPPORT DILEMMA**

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**EVOLUTION OF SELF-PROPELLED HOWITZERS**

Cannon-based artillery has long been the primary means for ground combat maneuver forces, including armor, infantry, cavalry, airborne, and air assault, because of its ability to deliver accurate fires at relatively long ranges. The self-propelled howitzer (SPH) had its origin in World War I, when a few experimental mounts were tested with medium-caliber cannons rigged on tractor chassis. By the end of World War II, SPHs were becoming common in the armored and mechanized forces of Western (i.e., the British, French, U.S., and German) armies.

In spite of the technical advance the SPH represented, the tactics and procedures employed in the early self-propelled units were virtually identical to those used for the traditional towed-cannon batteries. For example, guns were placed roughly on line, normally in sight of each other, and the actions of the guns were closely controlled by the battery headquarters. The main advantage that the SPH batteries had over their towed counterparts was cross-country mobility. SPHs were also seen as providing at least some level of armor protection for crew and ammunition. Although technology was able to improve self-propelled artillery in different ways through the years, the fundamental operation of these battery formations paralleled that of the towed cannons from World War II until the early 1990s.<sup>1</sup>

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<sup>1</sup>Until the 1990s, the fire control and position/navigation technologies had not matured to a point that would enable individual guns to operate independently.

## USE OF SELF-PROPELLED HOWITZERS IN DESERT STORM<sup>2</sup>

During Desert Storm, the U.S. Army was equipped with 25 battalions of 155mm SPHs, generally consisting of M109 A2 and A3s. These howitzers were used for providing preparatory fires, direct support to maneuver, and, to some extent, counterfire. Although the ground offensive portion of Desert Storm was relatively short (roughly four days), the 155mm SPHs fired approximately 43,500 total rounds. About half of the rounds fired contained the dual-purpose improved conventional munition (DPICM) bomblets, about a third of the rounds fired were standard high-explosive (HE) rounds, and the remaining percentage of rounds (about 15 percent) were HE rocket-assisted projectiles (RAP) for extended range.

Across all howitzers, the average SPH fired only about 70 rounds during the ground attack operation; however, the six most active battalions (division artillery of the 1st Infantry Division, involved in the breach, and the 1st Armored Division) averaged around 130 rounds per howitzer. These SPHs provided extensive support to their maneuver elements, typically requiring between one and two full reloads from their resupply vehicles. Altogether in Desert Storm, the firing distribution among the different SPH units for fire support tended to be fairly uneven.

Prior to Desert Storm, several key shortcomings of the M109 series howitzer were noted. These included

- Firepower (rate of fire and range)
- Cross-country mobility
- Manpower requirements (e.g., lack of autoloader)
- Survivability from enemy counterfire.

Most of these key shortcomings were also apparent in Desert Storm. For example, with respect to the firepower shortcoming, the Iraqis had Russian and South African cannons with significantly greater ranges than the M109. Fortunately for coalition forces, they did not

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<sup>2</sup>Data on performance of U.S. SPHs in Desert Storm were collected from documents and interviews with artillery officers who fought in Desert Storm.

have the intelligence system needed to effectively acquire targets or an adequate command-and-control network for directing fires. Also, the U.S. M109s had frustratingly low firing rates, particularly for firing preparations. However, this shortcoming did not turn out to be of much consequence because the ground commanders were able to call on additional tubes (cannon and rocket) beyond the normal division allocation.

One of the most prevalent observations was that the cross-country mobility of the M109s was inferior to that of the Bradley fighting vehicles and Abrams tanks. U.S. forces either had to move at the slower pace of the M109s or leave their cannons behind to catch up later.

With regard to manpower requirements, one U.S. artillery officer noted that when the M109 crews were engaged in fire missions, they were focused on the handling and preparation of ammunition. With their attention so engaged, they were not able to attend to local security of the battery.

SPH survivability did not become an issue because shoot-and-scoot operations were rarely exercised in Desert Storm. The inaccuracy of Iraqi fires and the effectiveness of the Multiple Launch Rocket System (MLRS) for counterfire reduced the need for quick movement from established fire positions.

## **PALADIN DOES NOT RESOLVE SHORTFALLS**

The U.S. Army's Paladin (M109 A6) was one of the first vehicles to integrate position and azimuth determining devices with systems that permitted on-board computation of firing data by individual howitzers. Paladin, conceived in the late 1980s and first fielded in 1993, is the latest and envisioned to be the last version of the M109 series. Operationally, it dramatically improves on the position, navigation, and fire control capabilities of its M109 predecessors. More specifically, it can receive fire missions via radio, quickly occupy a firing position, compute and automatically lay on firing data (since it has an on-board computer that provides data to automated azimuth and elevation drives), and quickly displace upon completion of the fire mission. Because Paladins can operate in small groups under a pla-

toon headquarters, there is no need for a traditional battery formation.<sup>3</sup>

Although the Paladin version of the M109 is seen as a dramatic improvement over earlier versions, ironically, it improves many aspects of the SPH that were not critical in Desert Storm. Since Iraqi counterfire was not effective for the reasons identified above, the need for rapid positioning, firing, and scooting (a key area of improvement for Paladin) was not considered to be essential.<sup>4</sup> The other key shortcomings of the M109 A2s and A3s experienced during Desert Storm—e.g., firepower, mobility, and manpower requirements—are not significantly enhanced by the Paladin version of the M109. Improvements in these areas are largely considered technical challenges because of chassis restrictions; the Paladin modifications are seen as taking the M109 chassis to the limit. And while some future modifications are possible, it is likely that further improvements will result in concessions that may have to be made elsewhere.

## CRUSADER IS A SYSTEM DESIGNED TO MEET NEAR-TERM FUTURE NEEDS

Crusader at the most fundamental level is a two-part cannon artillery system consisting of a self-propelled howitzer (SPH) and a versatile ammunition and fuel resupply vehicle (RSV). Figure 1 shows the proposed configuration of the system. Together these two vehicles represent a system that is unmatched by any other self-propelled cannon-based artillery system. The volume of fire deliverable by Crusader is expected to be markedly higher than any other cannon-artillery system in existence today or planned for the near future.

The primary reason for this unmatched capability is the combination of new technologies. In addition to an autoloader, a modular artillery charge system (MACS), and a multi-option fuze artillery (MOFA) in the SPH that allows for rapid initial, *surge* rates of fire, this

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<sup>3</sup>Smaller groupings of howitzers, required by increasing threats from counterfire systems, are becoming the norm in the artillery arms of the better armies around the world. While “traditional” gun batteries will be around for years to come in many armies, artillery will increasingly be small groups of weapons that present far less lucrative targets than the concentrated battery positions of the past.

<sup>4</sup>The M109s generally did not operate in shoot-and-scoot mode in Desert Storm.

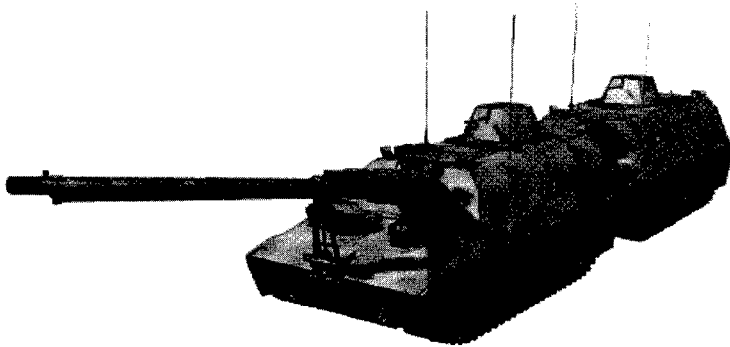


Figure 1—The Crusader Artillery System

system is envisioned to use active liquid cooling in the gun barrel, which will allow higher *sustained* rates of fire. Streamlined resupply methods in the RSV will allow simultaneous refueling and reloading operations that fully replenish the SPH in 12 minutes.<sup>5</sup> Although Crusader's solid-propellant gun cannot reach as far as the originally envisioned liquid-propellant gun,<sup>6</sup> it can still reach as far as most other SPHs currently in existence or in development. Also notable, Crusader uses new technologies that reduce its susceptibility to counterfire.

Altogether, Crusader employs a collection of new technologies that are envisioned to greatly improve on the capabilities available with Paladin (see Figure 2).

Crusader responds to the shortcomings noted for Paladin in many ways. Looking at the operational requirements document for Crusader, we note that it will significantly improve firepower and mobility (both in terms of offroad speed and dash capability), enhance survivability, and reduce manpower. Many of these improvements are synergistic and may result in further battlefield advantage, such as survivability enhancements resulting from smaller crews operat-

<sup>5</sup>A single RSV can also resupply more than one vehicle.

<sup>6</sup>Initial testing revealed that the liquid-propellant gun also fell well short of the required ranges, also lacking consistency of fires.

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**Crusader responds to Paladin's perceived shortfalls**

- Firepower
  - 2.5 times surge fires, 3 times sustain
  - 30–40% increase in range
- Mobility
  - 2.3 times greater power-to-weight ratio
  - ~30% greater dash distance (90-second interval)
- Survivability
  - Entire crew protected under armor
  - Susceptibility-reduction technologies
- Manpower
  - 30% reduction in crew (6 versus 9 for Paladin)
  - Automated loading/resupply

**Figure 2—Crusader Offers Significant Improvements in Key Areas**

ing fully inside the vehicle, greater dash speeds, faster attrition of the enemy, and special susceptibility-reduction measures.

On the downside, introducing the combination of new technologies imposes a significant penalty in the form of weight. Each of the Crusader vehicles weighs roughly 55 tons fully loaded, resulting in a total system that weighs about 110 tons. These weights are well within the bounds of existing heavy combat vehicles (e.g., M1A1 weighs roughly 70 tons), but the Crusader SPH is nearly twice the weight of the system that it replaces, the Paladin. In addition to its weight, which can increase supportability requirements, the acquisition cost has also been raised as an issue. The unit cost of the combined SPH and RSV is estimated to be about \$14.7 million.<sup>7</sup>

<sup>7</sup>U.S. General Accounting Office, *Army Armored Systems: Meeting Crusader Requirements Will Be a Technical Challenge*, Washington, D.C., GAO/NSIAD-97-121, June 1997.



## FOCUS OF THIS REPORT

Thus the Army faces a dilemma: continue with Paladin, a good system that has known shortcomings and that cannot reasonably be improved, or continue to invest in Crusader, which carries the risk of being too unwieldy to mesh with the Army's vision of how it will fight in future wars.<sup>8</sup> To resolve this dilemma, the Army has to address the issues of weight and cost along with a number of other issues that have been raised about Crusader and the need for it. RAND's Arroyo Center was asked by the Office of the Deputy Chief of Staff Operations to research some of these issues. Specifically, we were asked the following:

- What does Crusader provide to Army XXI?
- What increase in the application of fires does Crusader provide over current capabilities?
- What technologies does Crusader carry to the Army After Next (AAN) weapon systems?

To answer these three questions, we conducted an extensive evaluation of technical information available on Crusader and applied, to a limited extent, our high-resolution simulation and modeling capabilities.

## HOW THIS REPORT IS ORGANIZED

The rest of this report attempts to answer these questions as well as address other issues associated with the Crusader system. Specifically, Chapter Two summarizes the results of a survey of such foreign trends and developments and suggests the implications these systems may have for U.S. artillery. Chapter Three quantifies the fire-power that Crusader offers and explores a new mission for such fire-power. Chapter Four explores where Crusader and its technologies fit into the future of the Army, including the AAN. Chapter Five summarizes our research findings and concludes with our recommendations.

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<sup>8</sup>Or reexamine the acquisition of a foreign system.

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## THE EMERGING THREAT ARTILLERY ENVIRONMENT

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Our analysis of Crusader included a review of trends in world artillery and counterfire systems that will have an effect on U.S artillery in the future. This examination included the following areas:

- Foreign SPHs
- Target acquisition systems
- Precision munitions for counterfire.

This chapter highlights the results of a survey of foreign trends and developments in these areas and suggests implications that these systems may have for U.S. artillery.

### WORLDWIDE SUMMARY OF SELF-PROPELLED HOWITZERS

Paladin is an upgrade of the 1960s-era M109-series howitzer. While the vehicle includes a new turret, many components—such as the chassis, its automotive capability, and the level of protection it affords—are fundamentally the same as in the earlier versions of the M109. Today the technologies that Paladin helped pioneer are becoming increasingly common on more modern and capable self-propelled weapons being fielded around the world.

The main areas of improvement in modern SPHs include range, rate of fire, self-location, on-board fire control, level of protection, and ammunition-carrying capacity. A brief explanation of each area follows.

## Range

The quest for longer range is probably as old as cannons themselves. The current generation of SPHs becoming available in the world today are most often 155mm, with some 152mm weapons still being produced in the former Soviet bloc. Weapons of 39, 45, and now 52 caliber have become the standard. When employing base-bleed or rocket-assisted projectiles (RAP), these weapons can easily achieve ranges of 30–45 kilometers. Some howitzers are in the process of being refitted with longer-barreled weapons to extend their ranges. For example, the original version of the British AS 90 was armed with a 39-caliber tube (maximum range of approximately 30 kilometers with rocket-assisted munitions). In the near future, the British army will reequip its artillery regiments with 52-caliber tubes that will permit ranges of approximately 40 kilometers.

Increased range enables the weapon to cover a larger portion of the enemy target array, gives artillery units greater ability to provide fires for neighboring formations on their flanks, and improves the survivability of cannon units by permitting the guns to stand well back from the front lines, thus inhibiting the ability of at least some enemy systems from ranging the friendly gun positions.

With its 39-caliber tube, the Paladin is limited to a range, with rocket-assisted projectiles, of 30 kilometers—a range that is clearly on the low end of the capabilities of the modern generation of self-propelled weapons. Currently, the Army does not plan to refit Paladin with a longer gun tube. Such a modification could further strain Paladin's chassis and power plant, both of which are already near maximum capacity.

## Rate of Fire

Automatic loaders are becoming the norm in modern self-propelled howitzers. This capability gives the weapons a considerable "burst" rate of fire capabilities (6–8 rounds per minute for the first 2–3 minutes of firing is now common), and it decreases the physical strain on the gun crews by automating the process of moving heavy ammunition rounds. High rates of fire give cannon units the ability to maximize the number of shells they can place on a mobile, fleeting target.

High rates of fire can also minimize the exposure times of friendly weapons.

Paladin remains a manually loaded weapon. When compared with more advanced weapons, Paladin has a much slower rate of fire. High rates of fire will not always be needed. But in situations where such a capability is important, Paladin's manual loading system will constrain it.

### **Self-Location/On-Board Fire Control**

While Paladin may have been one of the first of the SPHs to demonstrate this capability, self-location and on-board fire control are becoming common features of modern self-propelled weapons. Even older howitzers are being modernized with add-on systems that enable individual guns to determine location and azimuth. For example, the Russian 2S19 152mm self-propelled howitzer is being retrofitted with positioning and navigation equipment and on-board fire control (largely intended for the export market).

One great advantage of these automated functions is unit dispersion. Self-propelled weapons no longer must operate in constricted, traditional battery positions. Greater dispersion means that artillery pieces are much less vulnerable to enemy counterfire. The challenges brought on by increased dispersion include resupply, coordination of the effort of weapons operating semiautonomously, and security from ground attack for dispersed guns that no longer have the protection offered by the traditional gun position.

Another key advantage of such automated functions is the ability to operate in "shoot-and-scoot" mode. With positioning and navigation equipment and on-board fire control, self-propelled weapons can quickly position themselves, shoot, and displace to alternate firing positions—potentially reducing their overall susceptibility to counterfire.

The important point to note is that Paladin no longer holds a significant advantage in this area. Some of the newer self-propelled weapons have position-locating systems only, without on-board fire control (relying instead on battery-level computation of firing data). However, the technology for on-board fire control and positioning

and navigation is proliferating, and many new guns have both capabilities.

### Protection

In today's terms, protection equates to armor. In the future, active protection systems may become common, but that is not the case today. However, significant amounts of armor impose a weight penalty. If that penalty is deemed acceptable, then the chassis, automotive system, and structure of the vehicle must be physically capable of bearing the weight of the armor. This is generally an area where tracked cannons have an advantage over lighter, and thus less protected, cannons on wheeled chassis.

Today the standard for protection is set by the new German PzH 2000 self-propelled 155mm howitzer. The Germans elected to provide PzH 2000 with significant amounts of passive and reactive armor. The weight of the vehicle—some 60 tons—reflects, in part, the weight of armor protection. Not only does PzH have a considerable thickness of basic armor plate on its roof, it also includes several tons of reactive armor to defeat top-attack munitions.

While not up to PzH's formidable protection standards, other modern self-propelled howitzers also include fairly high levels of armor protection. This means that designers and users have accepted the weight penalty associated with armor. Considerable attention is now being given to protection against top-attack submunitions, as evidenced by PzH's armor array.

Mines can also present a serious threat to armored vehicles. In operations other than war, mines could represent a particularly important challenge. The 1960s-era M109 chassis that Paladin is based on offers relatively limited protection against mines. Future combat vehicles need to address this problem.

Paladin is the final evolution of the basic 1960s M109 chassis, which employed considerable amounts of relatively thin aluminum armor in its structure. Paladin's protection level is, therefore, less than the more modern, heavier, self-propelled howitzers being developed and fielded around the world.

### **Ammunition-Carrying Capacity**

The size of a self-propelled howitzer influences its on-board ammunition capacity. The greater the on-board ammunition capacity, the greater the mix of ammunition types and the less frequent the need for resupply. Table 1 shows the ammunition-carrying capacity of a selection of modern self-propelled weapons.

It should be noted that the modern generation of howitzers, exemplified by those shown in Table 1, represent the weapons available to the better armies of the world. Many of the potential opponents of the United States will retain older weapons that are not capable of the highly dispersed, decentralized operations that self-location systems allow. Years from now, many of the artillery units in the Third World will still deploy in "traditional" battery positions of World War II. Additionally, just because a Third World army purchases quantities of very-long-range cannons, that does not mean they can effectively employ them in an overall fire support *system*.

Altogether, it is evident that considerable increases in capability have been made in the generation of modern SPHs that have been fielded in recent years or are about to enter production. The trends are all toward increased range, greater rates of fire, the ability to operate in highly dispersed modes via self-location and on-board fire control systems, better protection of the vehicle, and somewhat increased ammunition capacity. Paladin remains a very capable weapon, but it is increasingly clear that it is no longer on the leading edge of howitzer development. Indeed, in many of the categories listed above, the U.S. Army's premier artillery piece is outclassed by the more modern weapons entering foreign service.

### **PROLIFERATION OF TARGET ACQUISITION SYSTEMS**

As mentioned previously, just because a Third World army buys long-range cannons, the acquisition does not necessarily translate into a formidable fire support system. An important factor is the ability to acquire targets. The Iraqi experience in 1991 is illustrative. Although it had large numbers of long-range guns, the Iraqi artillery was, in many cases, firing blind. Inadequate target location capability combined with constant coalition air, artillery, and ground ma-

Table 1  
Foreign Systems—Possible Future Threats—Have Greater Capability Than Paladin

System/Country	Maximum Range (km)	On-Board Ammo	Maximum Rate of Fire	Loaded Weight (kg)	Speed (km/hr)	Crew Size	Year Intro
Paladin/USA	30	39	4	29,000	65 (30)	4	1992
PLZ45/China	39	30	4-5	32,000	56	5	1998
ZTS/Slovakia (W) <sup>a</sup>	40	40	6	28,000	80	4	1998
GCT/France	29	42	8	42,000	60	4	1978
PzH 2000/Germany	40	60	8-9	55,300	60 (46)	5	1997
Slammer/Israel <sup>b</sup>	40	75	9	60,000	45	4	1986
2S19/Russia	36	50	6	42,000	60	5	1989
LJW155/S. Africa	42	42	5	45,000	60	4	1998
AS90/UK	40	48	5-6	45,000	55	5	1992

SOURCES: Data compiled from U.S. Army Artillery School, National Ground Intelligence Center (NGIC), and *Jane's Armour and Artillery*, 1996-97.

<sup>a</sup>ZTS is a wheeled SPH.

<sup>b</sup>Exists as a prototype.

NOTE: Speed shown is onroad (offroad where data were available).

neuver attacks dramatically reduced the theoretical potential of Iraq's large artillery arsenal.

Over time, higher-quality target acquisition systems that could threaten U.S. artillery units will proliferate. If able to combine high-speed fire control systems with data from target acquisition means, and quickly pass fire missions to cannon and rocket units, an opponent would pose a much greater threat to U.S. and allied artillery units than the Iraqis did in 1991.

The major areas of improvement in target acquisition include counterfire radars and unmanned aerial vehicles.

### **Counterfire Radars**

Whereas today many armies either totally lack these systems, or have early versions with limited capability (e.g., the 1960s-era British Cymbeline countermortar radar is illustrative of the systems currently found in Third World armies), over the next 10–15 years relatively advanced counterfire radars will become much more common. For example, several European nations are working on a counterfire radar that will be more capable than the U.S. Firefinder series.

### **Unmanned Aerial Vehicles (UAVs)**

UAVs made an impressive combat debut in Israel's 1982 campaign in Lebanon. Nine years later, U.S. and coalition UAVs were employed for real-time target location in the Gulf War. Since then, many nations have become sold on the idea of UAVs. Many UAV programs are now in development around the world. These include systems with multiple types of sensors, ranges of hundreds of kilometers, the ability to loiter for several hours, and the capability to pass target-quality data, in real time, to artillery headquarters. While it will be years before UAVs are common, the trend toward proliferation is clear.

If combined with high-speed fire control systems that can process data from radars, UAVs, and other target-location systems, an opposing artillery system would be far more formidable than the one used by the Iraqis in 1991. The relative invulnerability that U.S. artillery



has enjoyed since the Korean War could be significantly compromised.

### **GREATER AVAILABILITY OF PRECISION MUNITIONS FOR COUNTERFIRE**

In the near term, the primary counterfire threat to U.S. artillery units would be cannon or rocket-delivered high explosive or, more likely, top-attack submunitions. The extensive passive and reactive armor array atop Germany's PzH 2000 epitomizes the concern generated by top-attack submunitions. Today, most cannons and rockets around the world can fire ammunition that delivers armor piercing top-attack submunitions.

A more serious threat than "dumb" submunitions has, however, already appeared. The National Ground Intelligence Center (NGIC) estimates that today 28 countries are involved in the production or development of artillery delivered high-precision munitions (ADHPM). Three basic types of munitions fall into this category:

- Sensor-fused "shoot-to-kill" (e.g., sense and destroy armor (SADARM)-type under development in Russia, France/Sweden, Germany, the United States, and others)
- Terminally homing "hit-to-kill" (e.g., Russian 152mm "Krasnopol" laser-guided projectile, and French terminally homing rocket munitions)
- Course-corrected "area effect warhead" (e.g., Russian 300mm Smerch multiple rockets with midcourse correction that deliver top-attack submunitions, Sweden, France, United Kingdom, Israel, Germany, and others).

These munitions provide relatively high probabilities of hit/kill per round fired. While this class of munitions is just being fielded, over time (10–15 years) it is likely that they will become the counterfire munitions of choice among those armies that can afford them. With powerful submunitions or hit-to-kill warheads, it is problematic whether self-propelled howitzers will be able to carry sufficient amounts of passive/reactive armor to defeat this class of ammunition. As these weapons become relatively common, avoiding them

by means of “shoot-and-scoot” tactics, burst rates of fire that minimize the exposure times of firing weapons, active protection systems, and various concealment techniques will grow in importance.<sup>1</sup>

### IMPROVED FIRE SUPPORT APPEARS TO BE NEEDED

When compared with the modern self-propelled weapons that have been fielded in recent years by other nations, Paladin lags behind in several key criteria, particularly range and rate of fire. For several years, its position-locating and on-board fire control system will be competitive, but Paladin is no longer unique in those abilities. When compared with a new system like the German PzH 2000, Paladin appears to be at a significant disadvantage—PzH outclasses Paladin in virtually every meaningful category.

The trends in counterfire systems around the world are threatening. As counterfire radars and UAVs, for example, become more common, an opponent *who has successfully integrated these capabilities into his fire support system* will be able to place U.S. artillery units at significant risk.

Munitions-development trends also pose growing threats to U.S. field artillery units. Top-attack submunitions are already common. In coming years, “smart” counterfire munitions will be increasingly available.

This is not to say that every potential opponent will gain the ability to put U.S. artillery at great risk. Integrating new cannons and rockets together with modern target acquisition and fire control systems and improved ammunition challenge many potential opponents. Nevertheless, as time goes on, the technologies and weapons to threaten U.S. artillery will be increasingly available to possible adversaries, as evidenced by the trends and examples that were highlighted in this chapter.

As the capabilities of foreign SPHs continue to outpace Paladin and as sophisticated counterfire technologies proliferate, it will be impor-

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<sup>1</sup>Sources for this section include *Jane's Armour and Artillery*, 1996–97 and earlier editions, data provided by the U.S. Army Field Artillery School, and information provided by the National Ground Intelligence Center.

tant for appropriate enhancements to be made in the U.S. artillery arsenal. Additionally, the proliferation of ADHPMs will create new challenges for SPH survivability. Given these, Crusader represents one possible solution.

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## **CRUSADER OFFERS CONSIDERABLE FIREPOWER IMPROVEMENT**

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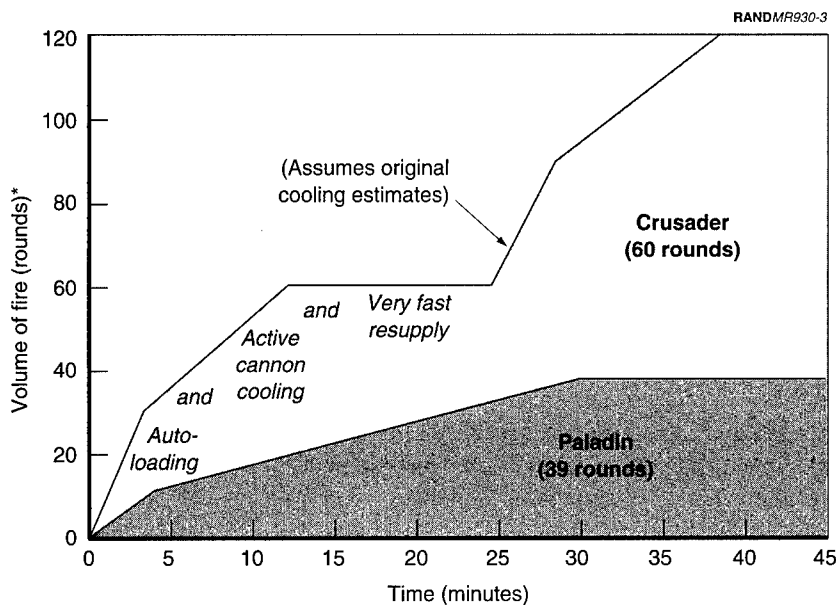
This chapter assesses the firepower that Crusader offers over Paladin through a comparison of volume, range, and responsiveness of fire and explores a new mission that can be considered for SPHs given such firepower and capability.

### **GREATLY IMPROVED APPLICATION OF FIRE**

Crusader is expected to produce a much greater volume of fire over Paladin due to a number of factors: the autoloader provides fast assembly and loading of rounds, active (pumped) liquid cooling of the gun reduces temperatures below that at which charges "cook off," and automated resupply from the RSV reduces the 60-round reload/refuel time to 12 minutes (about half the time for Paladin to reload only).

Figure 3 illustrates how the volume of fire from a single Crusader system is substantially higher in both short few-minute periods such as shoot-and-scoot and in longer-duration high-volume missions where the SPH might be stationary. The curve for Crusader levels off at 13 minutes because by then it has expended its store of ammunition and does not begin firing again until it has been resupplied at 25 minutes. The ability to begin firing again assumes that the original performance estimates for the active cooling system hold.

In addition to firepower, Crusader also offers much greater range and better overall responsiveness. It should be noted that the RSV also is being planned with a refueling capability, so it will be able to bring ammunition and fuel simultaneously to the Crusader howitzers.



\*Cumulative rounds deliverable per SPH; theoretical maximum per SPH from available data.

**Figure 3—Crusader Firing Rates and Resupply Allow High Volumes of Fire**

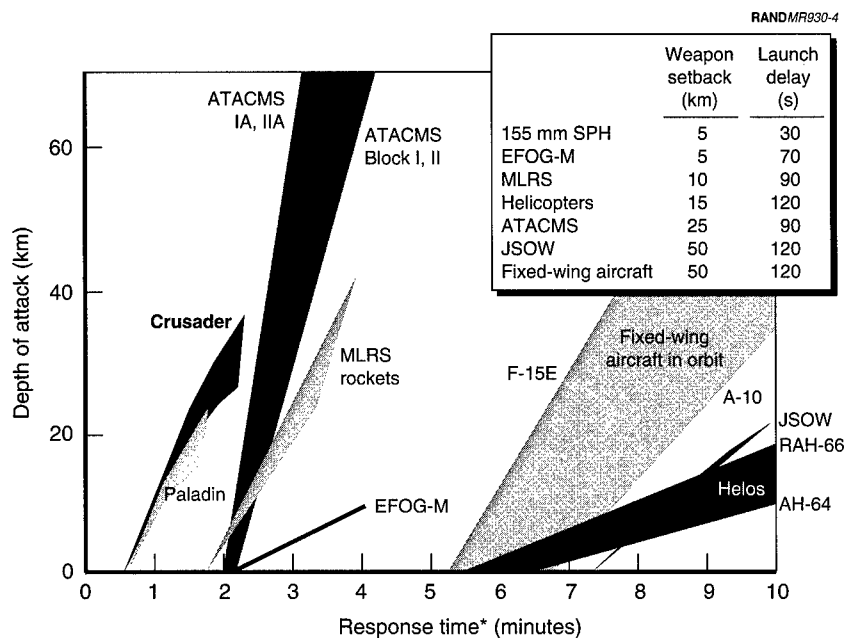
Drawing on previously published research,<sup>1</sup> Figure 4 shows the difference between Crusader and Paladin's response time and range to target. Most notable is the large difference in range. With Crusader's 40-kilometer range, it even begins to rival the ability of the MLRS rocket artillery.

Examining the bigger picture, Figure 4 also shows the range and responsiveness of different weapon system options for fire support in general. It depicts the characteristics of a wide range of other systems, including cannons, rockets, missiles, fixed-wing, and rotary-wing aircraft. Many of these systems are able to carry substantial

<sup>1</sup>J. Matsumura, R. Steeb, T. Herbert, M. Lees, S. Eisenhard, and A. Stich, *Analytic Support to the Defense Science Board: Tactics and Technology for 21st Century Military Superiority*, Santa Monica, CA: RAND, DB-198-A, 1997 (also published in *DSB Summer Study*, Volume II, Chapter 6).

payloads and deliver them with high accuracy, but only cannons have the ability to engage fleeting targets successfully in the direct support mission of maneuver forces. Part of this capability is because cannons can be sited close to the FLOT, part is because they can be laid and aimed quickly and accurately, and part is due to their very fast projectile speed (Mach 2–3) resulting in very short flyout times.

Generally, Crusader further improves the cannon edge by providing much greater volume of fire, increased range, and slightly faster fly-out times than Paladin. These improvements could be used in several ways. Typical missions—preparatory fires, general support, counterfire—could be accomplished more quickly than is possible with current capabilities, thus facilitating faster tempo and increas-



\*Does not include command and control delays, which can be highly situation dependent.

**Figure 4—Crusader Improves the Responsiveness and Range of Cannon-Based Artillery**

ing the shock effect on the enemy. Alternatively, missions could be carried out over a broader area in the same time that current capabilities can, reducing the intensity of ensuing direct fire battles and reducing the need for mutual support among units. Greater mission scope could also lessen the requirements for close air support and free other assets such as MLRS for other missions. Finally, the efficiency of Crusader may allow a battery to carry out the mission of a battalion, or a single gun to replace a platoon, so that force size, logistics burden, and deployment load may be reduced.

This added capability, along with other inherent cannon advantages such as firing a wide variety of munitions, should allow Crusader to shoulder a greater range of missions than normally considered for cannon artillery. *In light of existing analyses, we see this as a distinct point to emphasize—rather than treating Crusader as a direct replacement for Paladin—because of its greatly improved capability, one can begin to postulate new missions that might not have been possible with the Paladin system or other SPHs for that matter.*

### A NEW OPPORTUNITY? COUNTERING ENEMY MRLs

One such example of a new opportunity might be to consider using Crusader to attack multiple rocket launchers (MRLs). Although the current response might normally involve using MLRS to counter enemy MRLs,<sup>2</sup> the Crusader has a number of favorable characteristics that enable it to counter this type of threat. These characteristics include fast response, high volume of fire, high levels of accuracy, and the option to be forward positioned (unlike MLRS, Crusader has reasonable levels of self-protection, including armor and the M2 .50-caliber machine gun). This ability to position forward makes the system more responsive, which can also result in greater volume over fleeting targets and better overall accuracy.

As an example, we examined Crusader as a possible response to a current-day threat situation posed by 240mm MRLs in North Korea. This weapon poses a significant threat, in that a very large number of 240mm MRLs are poised north of the demilitarized zone (DMZ) and

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<sup>2</sup>Previous work by the Joint Precision Strike Demonstration Project Office has analyzed MLRS options for countering the 240mm MRLs in an NEA scenario.

are targeted toward South Korean urban areas and military targets. These launchers can fire a first strike of many thousands of missiles and return in a few minutes to protected caves or to alternate firing positions. We felt that this scenario, used to examine options in the Rapid/Precision Counter MRL advanced concept technology demonstration (ACTD), would be useful for illustrating the advantages and disadvantages of systems such as Crusader for engaging fleeting, agile targets. It assumes the fire support systems are in place and forward positioned near the DMZ.

The Northeast Asia (NEA) scenario specifies that MRLs move out from underground facilities (UGFs), fire from preplanned firing positions, and return to the UGFs. Examination of the available data on the UGF sites suggests that a number of possible "exit and return" methods for the MRLs may be possible. In this case, the launchers move directly from the firing points to the UGFs. This procedure makes it difficult to target the launchers, because once they fire it only takes 75 seconds to return to their UGFs.

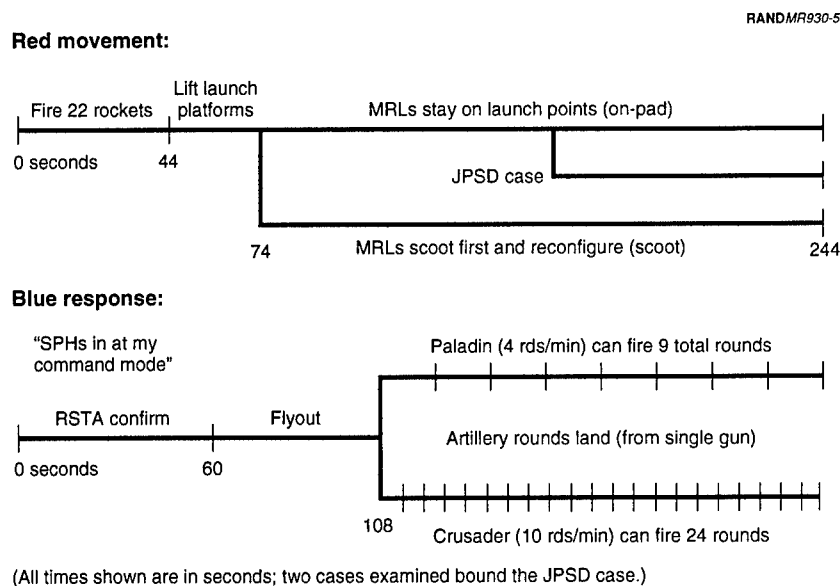
The timelines for Red movement and Blue response, shown in Figure 5, are very challenging. The upper set of Red movement lines shows that the MRLs can fire their complete set of rockets in 44 seconds. Data from the Joint Precision Strike Demonstration Project Office indicates that the crew then needs two minutes to lower the launcher, raise the stabilizing pads, and quickly return to the UGF. This scenario is depicted on the chart as "JSPD case" and shows a total exposure time of 164 seconds. However, it is possible that the MRLs could displace faster than the JSPD case or that they might take longer. Accordingly, we diagram and simulate two cases that bound the JSPD scenario. On the upper line, they are stationary at or near the launch pads some 200 seconds after firing. On the lower line they have moved back after only 30 seconds, and are near the UGF for the same period.

The lower portion of timelines shows Blue responses for Crusader and Paladin. Sixty seconds are assumed for Firefinder backtracking and communication to the howitzer platoon (three howitzers). The cannons are already targeted toward specific sites, so that firing and flyout takes about 48 seconds. The first round for either Paladin or Crusader lands at about 108 seconds, but Paladin is able to fire only 9



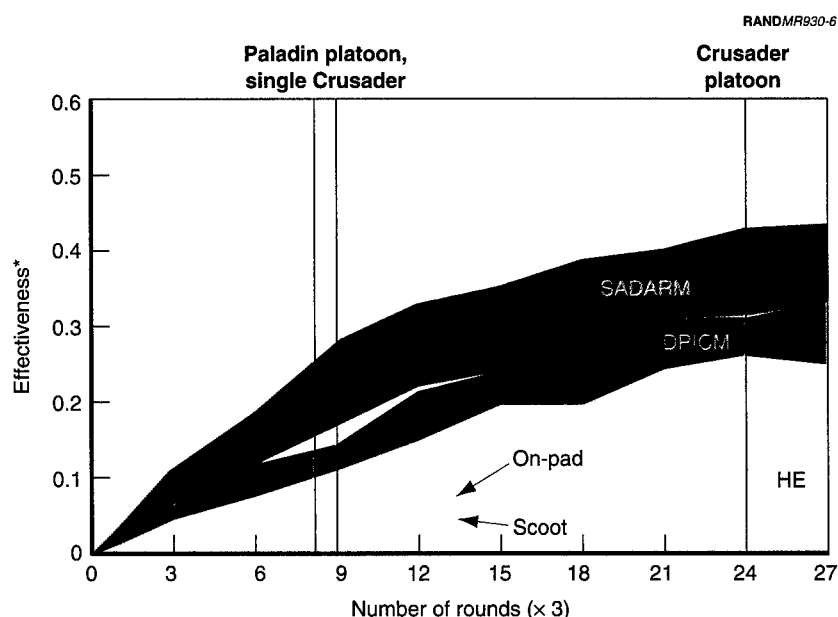
rounds (at surge rate) compared with 24 rounds by Crusader before the MRLs take cover.

The relative effectiveness of the two cannon systems depended on which munitions were fired and whether they caught the targets on the launch pads or on the move. The lower curve, shown on Figure 6, represents the effectiveness<sup>3</sup> of high explosive (HE) rounds, the top edge delineating efficiency against on-the-pad targets, with decreasing efficiency against scouting targets shown by the lower edge. This is not the recommended munition against this type of target and did poorly compared with DPICM and SADARM (which has a relatively small footprint). In all cases, the greater number of rounds fired by Crusader ( $24 \times 3$  cannons) resulted in significantly more hits



**Figure 5—Assumed Timelines for Red Movement and Blue Response**

<sup>3</sup>Effectiveness is shown for comparative purposes; it comprises a number of components, including the round's ability to encounter the target set along with the probabilities of acquisition, hit, and kill (as appropriate for smart and precision weapons).



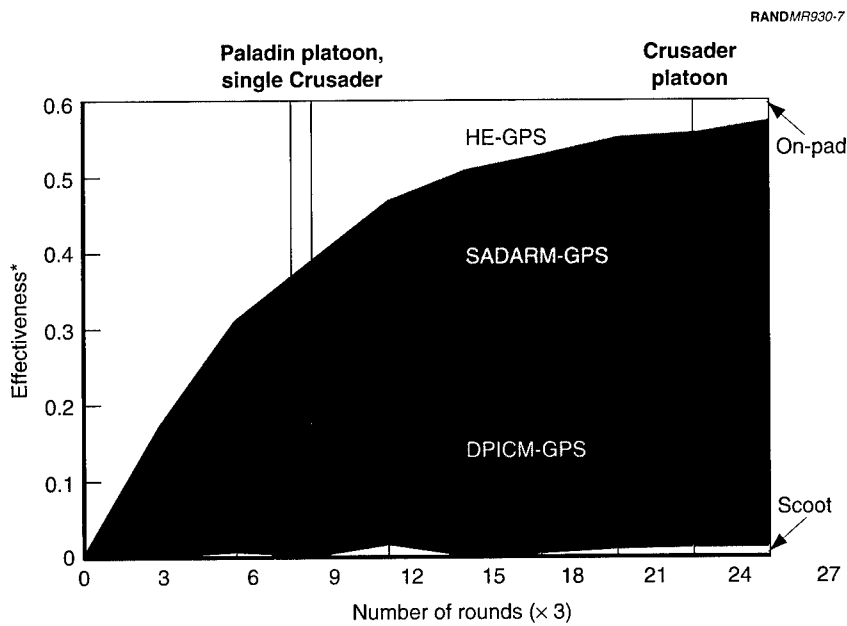
\*At predetermined range.

Figure 6—Both Munition Types and Platforms Define Mission Effectiveness

than Paladin could achieve. Decreasing marginal returns with more munitions were seen, of course, due to overkill of targets and hulks. Interestingly, a single Crusader could achieve almost the same effectiveness as a platoon of Paladins.

As a next step, we examined the effect of adding GPS guidance to the rounds in the same situations.<sup>4</sup> Here, HE with GPS was extremely efficient when the launchers were caught on the pads; however, it completely missed in the case where the MRLs are moving rapidly back to the UGF (Figure 7). DPICM exhibited much the same behavior, while SADARM, with its somewhat larger footprint, was able to perform relatively well in either stationary or scoot conditions. Again, Crusader's higher rate of fire increased effectiveness of the

<sup>4</sup>Where GPS guidance might be proposed as a potential solution to this problem.



\*At predetermined range.

**Figure 7—GPS Guidance Can Improve Mission Effectiveness When Targets Are Stationary**

mission, but to a lesser extent than with unguided rounds. So although GPS guidance provides a solution in some cases, it may represent only a partial solution in difficult circumstances.

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## WHERE DOES CRUSADER FIT IN THE FUTURE OF THE ARMY?

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One of the key arguments for Crusader is that it can act as a “technology carrier” for many new systems now in development. Thus it might act as a development vehicle for demonstrating and refining technologies such as active protection systems, enhanced protection against mines, situation awareness displays, and advanced mobility systems. Figure 8 lists more comprehensively the technologies noted in Crusader documents and briefings. Many of these enhancements

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**Crusader is envisioned to employ a number of new technologies\***

- Automated situation awareness and decision aids
- Hit/detection avoidance
- Long-barrel, liquid-cooled cannon
- Embedded diagnostics and logistics
- Advanced armor and configuration
- Improved mobility and suspension
- Projectile tracking
- Modular artillery charge system/autoloading
- NBC protection
- Automated resupply/refuel operations

\*Derived from U.S. Army Artillery School and PM Crusader information/documentation.

**Figure 8—Technologies That Crusader Can Potentially Carry**

should transfer to other future combat vehicles. At the same time, Crusader's pioneering systems may allow it to remain effective through the Army XXI period and well into the AAN era. This chapter offers some subjective assessments of the importance and applicability of key Crusader technologies for these time frames.

### DELIVERY SCHEDULE PUTS CRUSADER IN BOTH ARMY XXI AND AAN FORCES

Acquisition timelines projected for Crusader and Paladin show that both of these systems may be operational well into the future. As shown in Figure 9, Crusader is expected to be produced from 2006 to 2012 and should be in the force during the eras of both Army XXI and AAN. Paladin continues in production through 1999 and should be operational through Army XXI and be phased out in the early part of AAN. Crusader appears to mesh well with Army XXI concepts, but plans must be made for how to integrate the heavy Crusader with the agile forces currently envisioned for AAN.

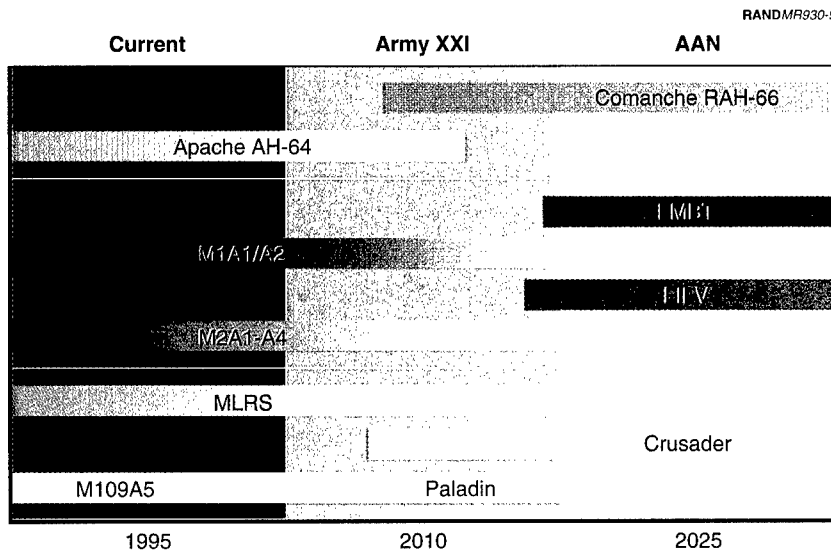


Figure 9—Crusader Fielding Puts It in Line with Supporting Army XXI and Army After Next Forces

It should be apparent from the timelines that if Crusader is not bought, there may be a shortfall in capability with Paladin for several decades. Any follow-on system may then have to compete for scarce acquisition dollars with block improvements for the MLRS replacement system, the future infantry fighting vehicle (FIFV), and the future main battle tank (FMBT).

#### **CRUSADER TECHNOLOGIES MAY APPLY TO THE AAN ERA**

As currently envisioned, the AAN concept is a revolutionary approach to battle. One of the fundamental requirements of AAN is operation at a very high tempo, with agile, air-mobile battle units operating over large areas. These units are expected to coordinate with heavier Army XXI exploitation units to outmaneuver and shock the enemy with quick thrusts and massed fires. The forces will also rely on information dominance and integrated operations to gain comprehensive situation awareness while denying the enemy knowledge of our actions.

Several Crusader technologies were determined to have a high degree of applicability to the AAN battle force, as shown in Table 2. These are ranked "high" in the AAN column of the chart. Because accurate, real-time information will be a fundamental requirement for AAN forces, capabilities such as automated situation awareness and embedded diagnostics will be critical. The more lethal future battlefield will also place a premium on quality nuclear-biological-chemical (NBC) protection and on detecting and avoiding hits.

Other Crusader technologies such as advanced armor and improved mobility should be important for future combat vehicles, such as the future tank and infantry fighting vehicle, but they may have less importance for the lightweight air-mobile elements of AAN battle units.

Probably of less importance to AAN are technologies such as Crusader's liquid-cooled cannon and projectile tracking system. This is because smart and brilliant munitions are expected to proliferate and may offset some of the need for cannon accuracy and volume of fires.

The automatic loader and automated resupply technologies, finally, appear to have indeterminate values to AAN. These may be useful

Table 2

**Subjective Assessment of Technologies That Crusader Can Carry to Army XXI and Army After Next Forces**

Technology Areas	Relative Applicability		
	Current	Army XXI	AAN Battle Force
Automated situation awareness and decision aids	High	High	High
Hit/detection avoidance	Low	Medium	High
Active liquid-cooled, long-barrel cannon	High	High/Medium	Low/?
Embedded diagnostics and logistics	High	High	High
Advanced armor and configuration	High	High	Medium
Improved mobility and suspension	High	High	Medium
Projectile tracking	High	Medium	Low
Modular artillery charge system/autoloading	High	High	?
NBC protection	Medium	High	High
Automated resupply/refuel operations	High	High	?

for other indirect and direct fire systems, or there may be increasing emphasis on rocket and missile systems. Alternatively, gun technology may evolve to electromagnetic or electrothermal systems.

These advanced technologies do not obviate the issue that weight remains a major problem for Crusader in the AAN battle force concept. At roughly 55 tons each for the platform and supply vehicle (combat loaded weight), the concept does not mesh with the planned 15-ton airliftable vehicles associated with AAN.<sup>1</sup> The technologies and architecture of Crusader would have to be completely rethought to move it into a lower weight class.

<sup>1</sup>Looking out 20 to 30 years from now, legacy systems will likely be a major part of the ground force even in the AAN vision. Although Crusader may not be suitable for providing support to this new class of AAN air-mechanized combat vehicles (or other more conservative alternatives), it will likely serve well in supporting legacy systems for which it was designed.

However, Crusader may be able to make up for some portion of its weight penalty because its expected capabilities should result in new opportunities for force reorganization, shifts of responsibilities, and changes in tactics. In themselves, these may change the acquisition picture for the Army XXI and AAN time frames. Also, it is possible that in the early years of the AAN time frame the armored and mechanized units equipped with the FMBT and the FIFV will have to accommodate their tactics to the strengths and limitations of the Crusader system.

Looking to the future, however, Crusader's greatly increased firepower could be used in several ways. Typical missions—preparatory fires, general support, counterfire—could be accomplished more quickly than with current capabilities, facilitating faster tempo and producing greater shock on the enemy. Alternatively, missions could be carried out in the same time that current capabilities can, but over a broader area, reducing the intensity of ensuing direct fire battles and lessening the need for mutual support among units. Greater mission scope could also lessen the requirements for close air support and release assets such as MLRS for other missions. Finally, the efficiency of Crusader may allow a battery to carry out the mission of a battalion, or a single gun to replace a platoon, so that force size, logistics burden, and deployment load may be reduced.

## **CLOSE-IN FIRE SUPPORT MAY BE CHANGING IN THE FAR FUTURE**

Although our analysis suggests that Crusader represents a dramatic improvement within current cannon capabilities, we also note that the role for cannons in general may be changing. Specifically, one of the unique niches for cannon fire in the current environment is providing *direct support to maneuver operations*. However, a number of new initiatives, if successful, can reduce the need for such fire support. Many of these initiatives envision aggressive use of emerging long-range precision-guided weapons, where these weapons have the potential to reduce greatly the intensity of the close fight, thereby decreasing the need for associated close-in fire support.

For example, last year's Defense Science Board Task Force on Tactics and Technologies for 21st Century Military Superiority examined,



among other things, how remote systems could support a small, dispersed (very lightweight) force in the future. Weapons such as air-delivered standoff weapons and long-range missiles, both equipped with smart and brilliant submunitions, were considered key systems to provide fire support in the future. Similarly, Defense Advanced Research Projects Agency's (DARPA) Small Unit Operations and the AAN initiative, which both represent dramatically new visions of how ground warfare might change, involve the aggressive application of comparatively small and very lightweight units that use a number of highly advanced indirect fire support options (e.g., the Army Tactical Missile System (ATACMS) equipped with brilliant anti-tank (BAT) submunitions launched from the Navy's Arsenal Ship).

Much of the emphasis in these future concepts is on conducting a greater portion of the battle from afar using these future long-range, high-tech weapons. Although there is an ongoing debate on how successful such a long-range fire support operation will be, especially in light of potential countermeasures, there tends to be a strong belief that these concepts coupled with the associated technologies can provide a more capable long-range fire support battle for the future.<sup>2</sup> In general, this kind of thinking implies a reduced or deemphasized close battle for the future and, thus, less overall need for direct, close-in fire support.

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<sup>2</sup>This is not to imply that there will not be a close fight, but the close fight as it is understood may be a smaller portion of the overall battle.

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**CANNON-BASED FIRES: LOOKING TO THE FUTURE**

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**OTHER POTENTIAL ALTERNATIVES TO CRUSADER**

Given its acquisition cost, timing, and the current budget environment, the need for Crusader among other U.S. Army priorities is likely to be examined and reexamined. On one front, many believe that cannon-based self-propelled fire support is essential to the future Army (as it has been for the past fifty years) but believe that either a Paladin, an improved Paladin, or foreign system (e.g., Germany's PzH 2000) can accomplish the job. However, others believe that cannon-based self-propelled fire support is less essential to the future of the Army, and they see advances in rocket artillery and submunitions (e.g., Inertial Navigation System (INS) or Global Positioning System (GPS) rocket guidance and increasingly brilliant munitions such as BAT P3I or Damocles) or new technologies such as fiber-optically guided missiles (e.g., EFOG-M) as being able to perform an increasing number of missions once accomplished by cannons.

In the first case, with respect to cannon alternatives to Crusader, a number of studies show the various merits and costs of such alternatives. Our assessment suggests that the current Paladin system is becoming outclassed by other systems. Limitations to the M109 chassis preclude key system-level modifications that would make Paladin competitive with the better foreign systems. To some extent, additional upgrades to Paladin may come at the expense or reduction of other key capabilities (e.g., a larger gun might further reduce mobility because of the greater weight).

Also, we did not come across any studies that show the tradeoffs associated with foreign systems. It has been established that many foreign systems, while having a number of desirable features, do not meet at least some of the requirements outlined in the operational requirements document (ORD). One of the notable foreign front runners, the PzH 2000, built by Wegmann & Co. GmbH, does not satisfy the requirements for extended-period rate of fire, fully automated operation, or connection to the U.S. Army's advanced field artillery tactical data system (AFATDS) fire control architecture. It also does not currently have a companion resupply vehicle.

However, discussions with Wegmann representatives suggest that they believe the PzH could be modified to meet the SPH requirements for Crusader. Additionally, PzH 2000 is expected to offer a number of favorable characteristics, including reduced gun overhang for maneuver operations in tight spaces, manual backup should electronics fail, and early availability. Such foreign systems may involve some key concessions, but they may also result in substantially lower acquisition costs.

To address the concerns about the future role of cannons in light of new and emerging concepts (e.g., the validity of the ORD) and the ability for alternatives other than cannons to provide capability, we did not find very much supporting analysis. Although one notable study performed by the U.S. Army Field Artillery school examines the need for cannons and rockets, this analysis primarily focuses on today's technology and does not include many of the planned improvements to rocket artillery or submunitions.<sup>1</sup>

Also, our examination revealed that little has been done in the way of force effectiveness analyses to address the presence of new technologies such as an EFOG-M or new systems such as Comanche to assume some of the missions that might involve cannons. On an even broader front, changes in Tac Air will have an effect on the close battle. New weapons coupled with planned aircraft have the potential to provide increased fire support; at the same time, there is much

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<sup>1</sup>U.S. Army Field Artillery School Study, *Cannon Vs. Rockets*, presented at RAND by LTC James Cummings.

rhetoric about reducing close air support in the future.<sup>2</sup> Regardless of whether more or less Tac Air will be available, the advantage that cannons have over aircraft in adverse weather conditions will likely remain well into the future. All these issues have implications that impact future SPH needs, both in character and number.

## **STRENGTH OF CANNONS IS VERSATILITY AND LOW-COST DELIVERY**

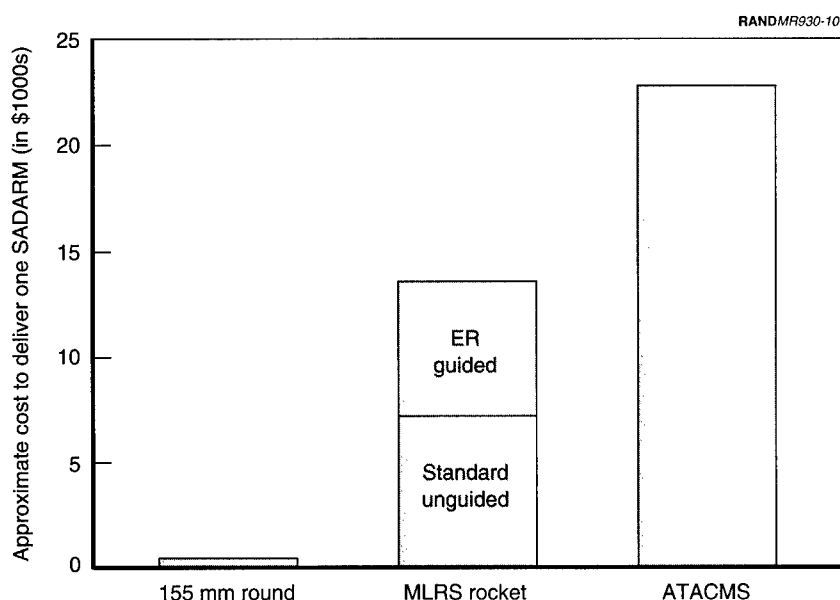
In light of the above, it is also important to emphasize that as new technologies such as rocket artillery evolve, they lack some of the advantages of cannons. For one, cannons provide a large degree of versatility. They can deliver a number of munitions including high explosive (HE), improved conventional munitions (ICM), dual-purpose improved conventional munitions (DPICM), Copperhead, sense and destroy armor (SADARM), and different types of mines. They can also deliver nonlethal payloads such as smoke and illumination rounds, which are often critical to the battle outcome but difficult to assess effectively in models and simulations. This versatility, along with their accuracy and the penetrating capability of the projectiles, makes cannons a key player in urban warfare. Extrapolating to the future, one can envision cannons as a key method for deploying sensor networks, communication relay nodes, and jammers because of their precision and efficiency.

Furthermore, cannons tend to be a less expensive option than rockets for delivering payloads. Figure 10 illustrates this point to an extreme by showing that the cost of delivering a single SADARM munition by cannon is considerably lower than by rocket (the figure does not include the cost of the platform and other prorated operational costs).

The SADARM version for 155mm cannon delivery is currently being produced in low quantities—a single 155mm round can deliver two SADARM. Although the MLRS version of SADARM has been canceled, it does illustrate the point being made here. The payload for a standard unguided MLRS rocket was six submunitions, four sub-

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<sup>2</sup>If close air support is reduced, the Army could require larger amounts of organic fire support in its units.



**Figure 10—Canon Delivery Cost of Munitions Is Much Less Expensive Than Rocket Artillery**

munitions for the extended-range (ER) guided rocket. Although the cost per submunition was often cited as an area of concern against the acquisition of SADARM (during the Milestone IIIA decision, SADARM was expected to cost around \$17,000 per submunition), it is evident that the cost to deliver the SADARM via MLRS would quickly approach the cost of the submunition itself. Taking this one step further, the cost to deliver the 31 SADARM via ATACMS<sup>3</sup> would have well exceeded the cost of the submunitions.

### CRUSADER'S ROLE IN THE FARTHER FUTURE

A number of different future concepts are assessing and even experimenting with revolutionary ideas for ground warfare along with aggressively applying new technologies. These concepts emphasize

<sup>3</sup>It has been estimated that 31 SADARM can be packaged into a single ATACMS.

smaller, lighter-weight, even air-mechanized forces that can deploy rapidly and fight with significantly larger amounts of remotely located fire support. Although these remotely located fires are, in concept, augmented by advanced organic fires, these organic fires are not generally provided by cannons. Rather, other lightweight, rocket-based systems are seen as providing much of the organic indirect fire. Thus, the future of cannons in these concepts is questionable.

However, as visible as these rocket-based future concepts are, their viability is still largely indeterminate at best. In the meantime, there is an operational need for responsive fire support. This need can potentially be met by Crusader. Further, cannon-based fire support historically has been seen as and in some cases proved to have been a major killer on the battlefield. While technology has the potential to change this view with new types of indirect fire alternatives (e.g., EFOG-M), many of these systems have yet to be demonstrated. Currently, ground forces rely on cannons to provide many types of fire support with many different objectives. A replacement for any aspect of the cannon fire support mission cannot be treated lightly.

Crusader appears to be a good match with the Abrams and Bradleys of the current force. Although such systems collectively will constitute the backbone of the fighting force through the Army XXI period, as the Army enters the next generation, such as the AAN era, the Abrams and Bradleys will most likely be phased out as the new combat vehicles such as the FMBT and FIFV enter the force. Because of the timing of its acquisition, Crusader is still likely to be in the force when this change takes place. However, it may not match well with highly mobile, possibly air-mechanized, systems envisioned for ground combat in the far future. Further, it is unclear how the fire support needs will change, given the many possibilities for new concepts in ground combat. Given this, some planning for uncertainty can be conducted, which might include revisiting the number of systems purchased or exploring potential modifications of or variations to the system.

While Crusader clearly has a place in the current Army and Army XXI, it is unclear how well it will fit in the future. Initial "signposts" suggest that the system may not constitute a match with many of the emerging concepts for ground warfare, particularly because of its

weight. Nonetheless, we note that such concepts have yet to be demonstrated; many of the technologies needed to get there are still unproven. The emerging light-force concepts being developed for the AAN period constitute the area where Crusader would have the greatest difficulty “fitting in.” It is, however, by no means clear yet how light forces of 20 or more years hence will be configured or how they will operate. The best use for the Crusaders that will be present in the first part of the AAN era will be to support future mechanized units. With the Army already planning for a follow-on for the Abrams and Bradley (both envisioned for the 2015–2020 period), it appears relatively certain that there will be future mechanized units of some form, in addition to the possible light air-mechanized units of AAN. As we have already pointed out, some of the technologies that are being developed for Crusader today will probably be transferable into the successors to the Abrams and Bradley. Here, several of Crusader’s components have the potential to serve as a starting point for demonstrating, developing, and refining critical technologies that can then be applied to a lighter-weight system for the future.

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